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BALL TEST APPLIED TO CEMENT MORTAR AND CONCRETE

BY
R. B. CREPPS
AND
R. E. MILLS

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ENGINEERING EXPERIMENT STATION
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Bulletin No. 12
ENGINEERING EXPERIMENT STATION

Ball Test Applied to Cement Mortar and Concrete

A Report of the Investigation
Conducted by
The Engineering Experiment Station
Purdue University

In Cooperation With
The United States Bureau of Public Roads

By
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Purdue University, LaFayette, Indiana
May, 1923

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BALL TEST APPLIED TO CEMENT MORTAR AND CONCRETE.

I. PREFACE

The ever increasing application of concrete as a structural material in building and in road construction has promoted extensive researches for the purpose of simplifying methods of testing and inspection. In this work the United States Bureau of Public Roads is cooperating with the Engineering Experiment Station of Purdue University and other organizations, this bulletin being produced under the joint working agreement.

This investigation was conducted primarily in an effort to establish a simple method of determining the mechanical properties of cement mortar and concrete. Incidentally a study was made relative to the effect of tire loads upon the hardness or surface strength of these materials.

Preliminary reports of the ball test as applied to cement mortar, at Purdue University, have been given by Dr. W. K Hatt in "Public Roads," Vol. 4, No. 7, November 1921, as published by the United States Bureau of Public Roads, and also in the Proceedings of the American Concrete Institute, Vol. XVIII, 1922.

II. INTRODUCTION

The Brinnell method of testing has been generally accepted as a reliable index of the mechanical properties of steel. In this test a definite load is applied to a standard ball and the depth of the indentation recorded as an index of the mechanical properties of the steel in question.

The principle of the Brinnell test as applied to wood has been investigated and used by Janka* and by the United States Forest Service.† In this method a cylindrical driving head is used, the penetrating end of which is a hemisphere, the load necessary to cause a definite penetration is recorded as an index of the mechanical properties of the wood.

In the development of a new and more convenient method of testing cement mortar and concrete the authors have made use of the Brinnell principle. In its application it is similar to that utilized in the wood tests, in which the depth of penetration is maintained a constant. The load on a steel ball necessary to cause a penetration equal to half its diameter is recorded as an index of the mechanical properties of the cement mortar or concrete.

In this series of tests a definite relation has been found to

*"Die Härte des Holzes" by Gabriel Janka, K. K. Forst-und Domänenverwalter: Mitterlung der K. K. forstlichen Versuchsanstadt in Mariabrunn. Wien, 1906.

†Forest Service Bulletin 108.

exist between the compressive strength and the ball resistance or the resistance of cement mortar to the penetration of a steel ball. The term, ball resistance, as used throughout this bulletin denotes the load necessary to cause a steel ball to penetrate one-half its diameter, and is a measure of some property connected with the surface strength or surface hardness.

By means of the ball test indications have been noticed concerning the effect of local overloads upon ball resistance of the mortar.

III. PROJECT

The data considered in this bulletin involves more than 2000 individual tests and embodies eight angles of procedure which are as follows:

1. Relation of compressive strength to surface hardness.
   - (a) Using standard ½ inch ball.
   - (b) Using balls of various diameters.
2. Area of contact of tires subjected to load.
   - (a) 34x5 inch solid rubber tire.
     - (1) New tire.
     - (2) Used tire.
   - (b) 32x4½ inch pneumatic tire with various inflations.
3. Effect of age and mix upon the surface hardness of cement mortars.
4. Effect of tire loads upon origi ıal surface of cement mortar.
   - (a) Solid tire.
   - (b) Pneumatic tire.
5. Effect of tire loads upon the original and exposed surfaces of cement mortars.
6. Surface strength at various points within the loaded area of contact.
7. Recovery in surface hardness of mortar subsequent to the application of tire loads.
8. Effect of tire loads upon a 1-2-4 concrete.

IV. APPARATUS AND METHOD OF APPLICATION

The apparatus consists essentially of a ½ inch diameter steel ball and a ¼x1½ inch washer through which the ball slips easily. See Fig. 1.

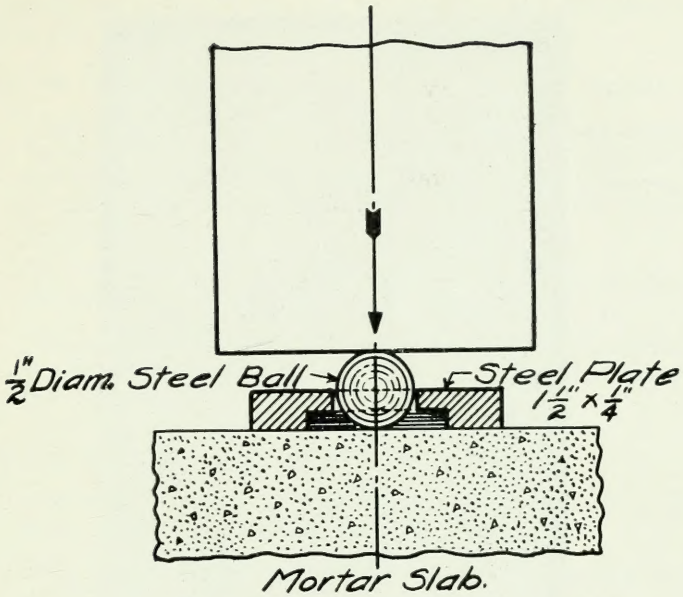

Fig. 1. Diagram Showing Ball Test.

The mortar slab under investigation rests upon the weighing platform of a testing machine. The ball and washer are placed upon the surface of the slab and load applied until the ball has penetrated ¼ inch into the mortar. At this point the head of the testing machine comes in contact with the washer, as indicated by the sudden rise of the scale beam. Deflectometers were sometimes used to measure the penetration of the ball.

Similar apparatus could readily be used for determining the strength of concrete structures and road pavements, the load being applied by means of a loadometer or an hydraulic jack.

Fig. 2 illustrates the typical surface of a specimen after the application of the ball test. The edges of the three depressions in the center of the slab have remained firm and sharp, indicating that the displaced material has been compressed into the body of the specimen without fracture to the surrounding surface. This surface condition is typical of the penetration tests on cement mortar or concrete which has not had previous application of tire loads. The remaining depressions on either end of the specimen indicate the resultant surface condition of cement mortar, which, previous to the ball test, has been subjected to tire loads varying in intensity from 400 to 5600 lbs. In these cases the surface adjacent to the point of penetration has chipped and disintegrated to some extent, which is the usual resulting condition.

Fig. 2. Photograph of a Test Specimen.

From an inspection of the ball impressions and observation of the data the following items are noted:

(A) For Original Mortar Surfaces Not Previously Loaded.

1. Generally the ball impressions remain firm and clear for mortars having a compressive strength up to 4800 lbs. per square inch, when the adopted ½ inch ball is employed. Occasionally the mortar chips adjacent to the ball impression.
2. The above statement also applies when balls of smaller diameter are used.
3. There is no apparent difference in the Ball Number regardless of whether or not the ball impression remained firm or chipped.

(B) For Mortar Surfaces Previously Loaded.

1. Generally the mortar chips adjacent to the ball impression. Occasionally the mortar does not chip.
2. This action occurs for mortar surfaces regardless of the amount of the superimposed wheel load.
3. The Ball Number is the same for a mortar regardless of the appearance of the resulting impression, whether it remained firm or chipped.
4. There is no apparent difference in the extent of chipping for small and large wheel loads.
5. No difference can be detected in the appearance of the ball impressions in a surface loaded with either the solid or pneumatic tires.

Typical penetration load curves are shown in Fig. 3. These curves were developed by recording the penetration of various sized balls upon the application of load in thousand pound increments. The penetration of each ball to one-half its diameter is indicated on the curves by a double circle. The curves rise abruptly at this point showing that the head of the testing machine has come in contact with the steel washer. Each point plotted represents one recorded value.

A one-half inch diameter ball was adopted as standard in securing the test data considered in this bulletin. It was found however, that the mass of the specimen somewhat limited the size of the penetrating ball, this being especially true in the case of building blocks and smaller specimens.

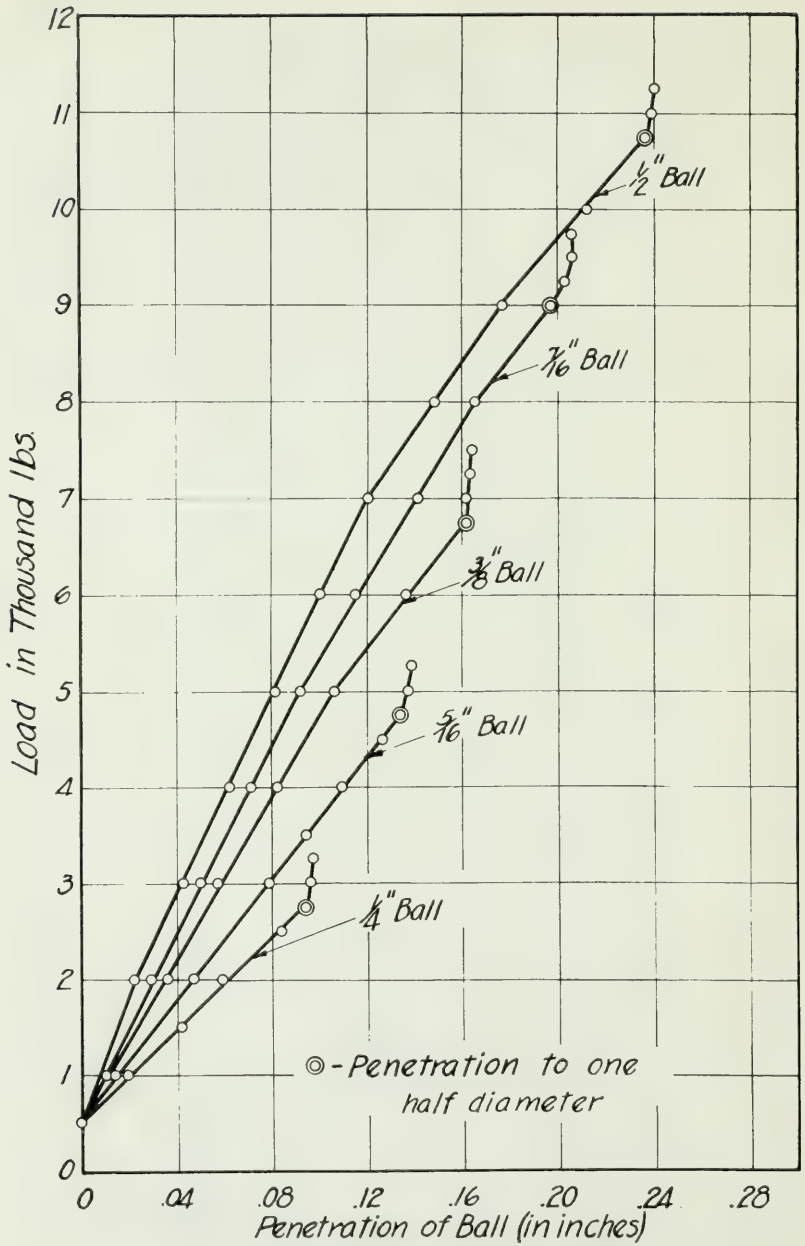

Fig. 3. Typical Penetration Curves.

V. MATERIALS USED

Cement

The cement was purchased from a local market at Lafayette, Indiana, and when tested according to the standard specifications for Portland cement, C 9-21, American Society for Testing Materials, gave the following results:

Table 1. **Test of Cement**

Brand	Per cent H_2O		Fineness	Time of set				Soundness	Tensile strength	
				Initial		Final				
	Normal consistency	Mortar		Hr.	Min.	Hr.	Min		7 days	28 days
A	23	10.3	20 4	2	30	5	00	O. K.	223	318
A	23	10.3	20.4	3	45	6	45	"	211	297
A	22	10.2	18 0	3	10	5	40	"	222	318
B	23	10.3	15.8	2	50	5	00	"	235	328
A	23	10.3	17.1	3	25	5	00	"	242	322
A	22	10.2	....	-	--	-	--	"	251	349

Sand

Washed sand was used, which was purchased from the Western Indiana Gravel Company at Lafayette, Indiana, and gave results as appear in Table 2 when tested on the Tyler Standard and United States Bureau of Public Roads standard sieves.

Table 2. **Mechanical Analysis of Sand**

(A) **Tyler Standard Sieves**

Total Per Cent Retained on Each Sieve

Sieve sizes	4	8	14	28	48	100
Per cent	1.1	5.4	25.6	69.7	95.3	99.1

(B) **United States Bureau of Public Roads Standard Sieves**

Total Percent Passing Each Sieve

Sieve Sizes	Circular Sieve	Square Mesh								
	$\frac{1}{4}''$	8	10	20	30	40	50	80	100	200
Per Cent	99.2	94.6	87.5	53.4	20.4	10.1	3.6	2.1	0.9	0.5

The sand weighed 105.5 pounds per cubic foot and had a fineness modulus of 2.96.

Standard tests were made to determine the tensile and compressive strengths of the sand which gave the following results:

Table 3. **Test of Sand**

TENSILE STRENGTH—Pounds per square inch

7 Days			28 Days		
Standard Ottawa Sand	Laboratory Sand	Ratio Lab. Sand to Ottawa Sand	Standard Ottawa Sand	Laboratory Sand	Ratio Lab. Sand to Ottawa Sand
218	304	1.39	326	432	1.32

COMPRESSIVE STRENGTH—Pounds per square inch

7 Days			28 Days		
Standard Ottawa Sand	Laboratory Sand	Ratio Lab. Sand to Ottawa Sand	Standard Ottawa Sand	Laboratory Sand	Ratio Lab. Sand to Ottawa Sand
1588	2044	1.41	2718	3400	1.26

VI. METHODS OF MAKING AND CURING TEST SPECIMENS

In order to facilitate loading of the specimens the same testing machine was used throughout the investigation. This, however, limited the size of the test slabs to 13x36x4 inches. Two $\frac{3}{8}$-inch reinforcing bars located one inch from the edges and one inch from the bottom and top respectively circumscribed the slabs. This provision permitted a premature handling of the slabs without danger of breaking. All specimens were thoroughly puddled in order to eliminate air cavities as much as possible. As a final procedure the surface was troweled only enough to make it smooth and level. The slump, as determined by a 4-8x12-inch cone, was maintained from one to two inches for all specimens.

One compression cylinder 6x12 inches was constructed with each slab to determine the compressive strength.

All test specimens were stored in the Laboratory and cured until the date of test by covering with damp sand or several layers of moist burlap. The temperature was maintained above freezing at all times and as near 70° F. as possible.

VII. TESTS AND RESULTS

Series 1. *Relation of Compressive Strength to Ball Resistance.*

Rigid rules and specifications have been generally adopted for concrete construction. Specifications of this nature require close inspection of the process of the work and product as well as of the materials involved and the life of the structure is in a great measure dependent upon the close observance of the construction

rules. The quality or strength of the finished product is ordinarily inspected by means of compression or tension tests of the material, duplicated in test specimens. This procedure, however, while furnishing an indication of the quality of the material actually in place, involves considerable time and expense as well. In the case of road pavements the actual material used may be tested by cutting compressive test specimens from the slab by means of a core drill and, while this method gives satisfactory results, its cost in time and money are very high.

The ball test, as an index of the compressive strength of the mortar of the concrete, eliminates many of the difficult features of the usual tests, since the finished product can easily be tested in place with negligible damage. In the case of a coarse aggregate in the concrete considerable care should be exercised in selecting a point for inspection, so that the ball does not rest directly upon a piece of the large aggregate.

Fig. 4 indicates the relation existing between the surface resistance or ball number and compressive strength. The Ball Number is that load divided by one hundred necessary to force the penetrating ball to one-half its diameter into the mortar. By means of this set of curves ball resistance can be readily converted into compressive strength values or vice versa. It will be noticed that in the case of each ball this relation is a straight line in which only the slope changes. A general equation may be written for the lines, which is of the form $S = MB - 380$, where S is equal to the compressive strength in pounds per square inch, M the slope of the line for any one ball and B the ball number.

The investigation of the above relation has involved more than one hundred individual tests and the points plotted in Fig. 4 clearly indicate that very consistent results were obtained. Both the compressive strength test specimens and slabs for the ball penetrations were constructed and cured under the same conditions, extreme care being exercised at all times to secure uniformity. The mixes varied from 1–1½ to 1–5 and the ages ranged from 3 to 35 days. Each point plotted in Fig. 4 represents an average of five ball number determinations and an average of five compressive strength tests. A general summary of the compression test results shows an average value of 10.4 per cent as the variance of any one test from the average of its group, while the ball number determinations show an average of 8.3 per cent.

It is necessary in the case of compression and tension tests to construct a number of duplicate specimens and to analyze and average the results in order to obtain reliable information. The same precautions are characteristic of the ball test, the results must be carefully analyzed and absurd values discarded.

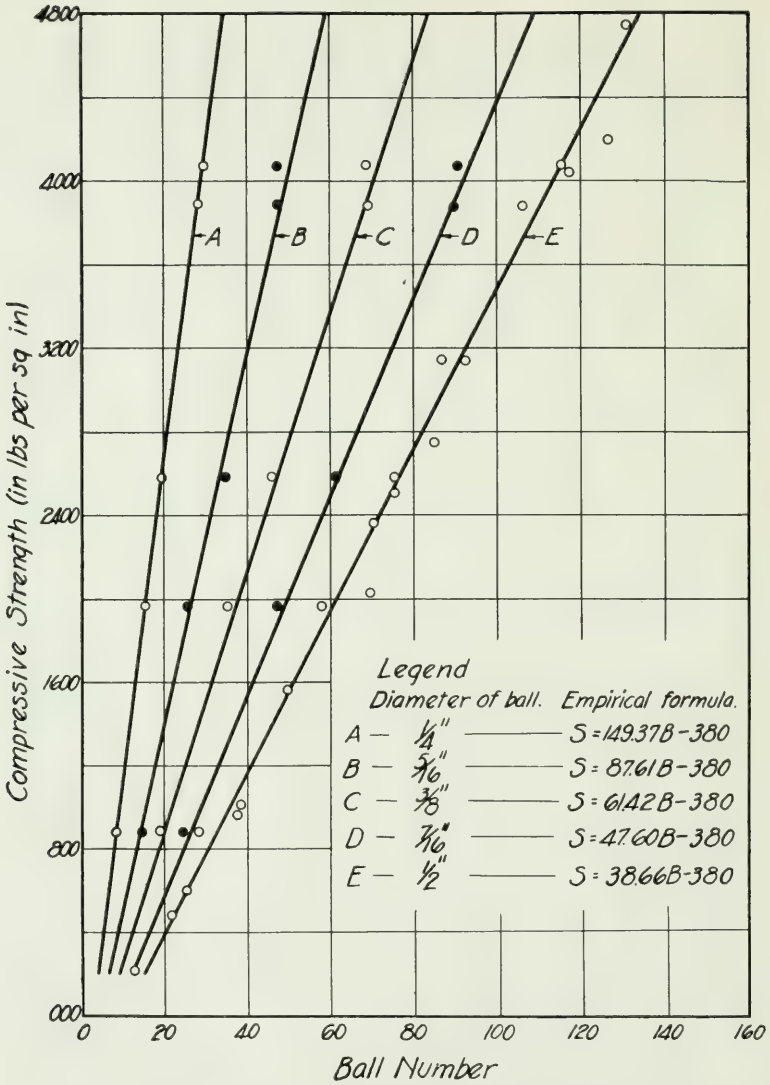

Fig. 4. Relation of Ball Number to Compressive Strength of Mortar.

Series II. Effect of Age and Mix Upon the Ball Resistance of Cement Mortars.

Relative ball resistance values of mortar at various ages as well as comparative values for different mixes have been developed by means of the ball test, results and curves of which

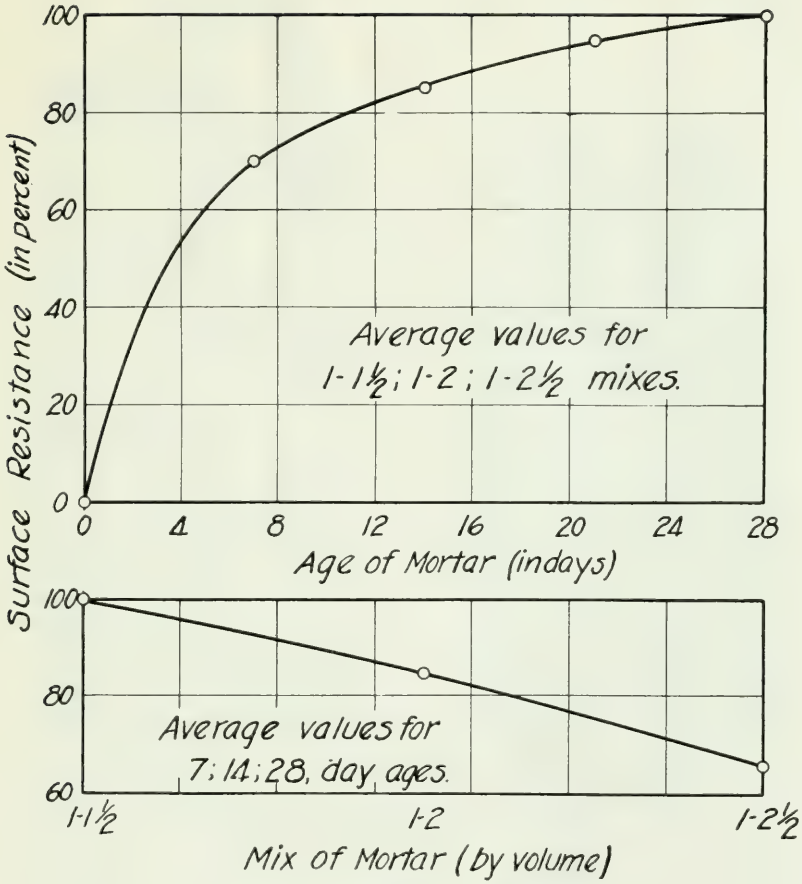

Fig. 5. Ball Resistance of Mortars.

are shown in Tables 4 and 5 and Fig. 5. The ball resistance of the mortar at the age of 28 days was arbitrarily taken as 100 per cent, and the resistance at any age less than 28 days is expressed as a per centage thereof. In the case of variable mixes 100 per cent represents the 1–1½ mix for ages 7, 14 and 28 days, other mixes being expressed as percentages thereof. Each point plotted in Fig. 5 represents an average of fifteen observations. A summary of the individual results shows an average value of 6.2 per cent as the variance of any one observation from the average curve.

Fig. 6. Typical Area of Contact for a Solid Rubber Tire.

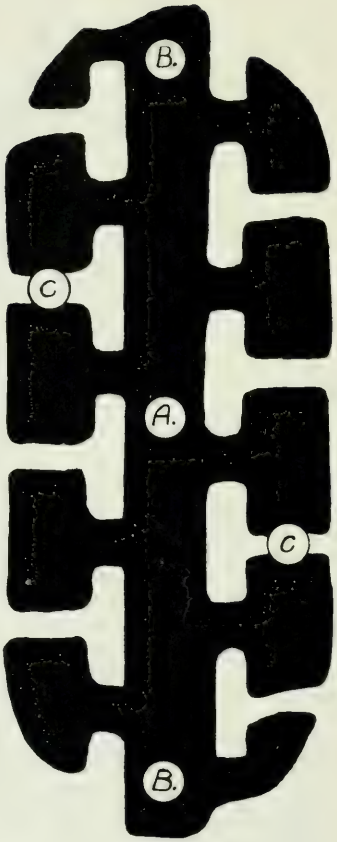

Fig. 7. Typical Area of Contact for a Pneumatic Tire.

Table 4. **Ball Resistance as Affected by Age**

Average Values for 1-1½, 1–2 and 1–2½ Mixes

Age Days	Per Cent Resistance
28	100
21	95
14	85
7	70

Table 5. **Ball Resistance as Affected by Mix**

Average values for 7, 14 and 28 days.

Mix	Per Cent Resistance			
	7 Days	14 Days	28 Days	Av.
1–1½	100	100	100	100
1–2	80	85.5	88.5	85
1–2½	60.5	69.5	69	66

Series III. Area of Contact of Tires Subjected to Load.

In order to study the relative effect of tires on mortar surfaces it is necessary to investigate the areas of contact for each type. Three types of tires were used as follows: (a) new solid tire, (b) used solid tire, (c) pneumatic tire. Figs. 6 and 7 indicate typical surface imprints of these tires subjected to the same external load of 1600 lbs. Fig. 8 illustrates the types of tires used throughout this investigation.

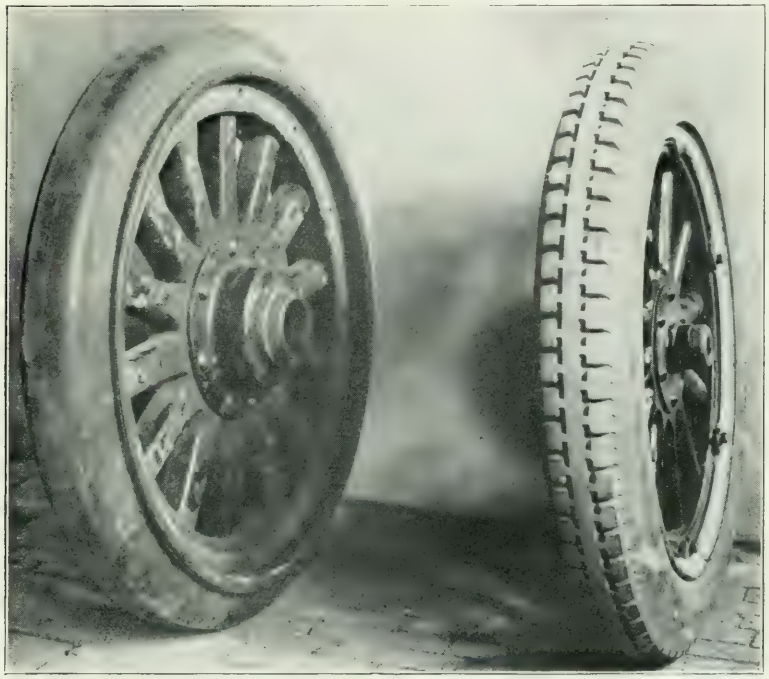

Fig. 8. Illustration of Tires.

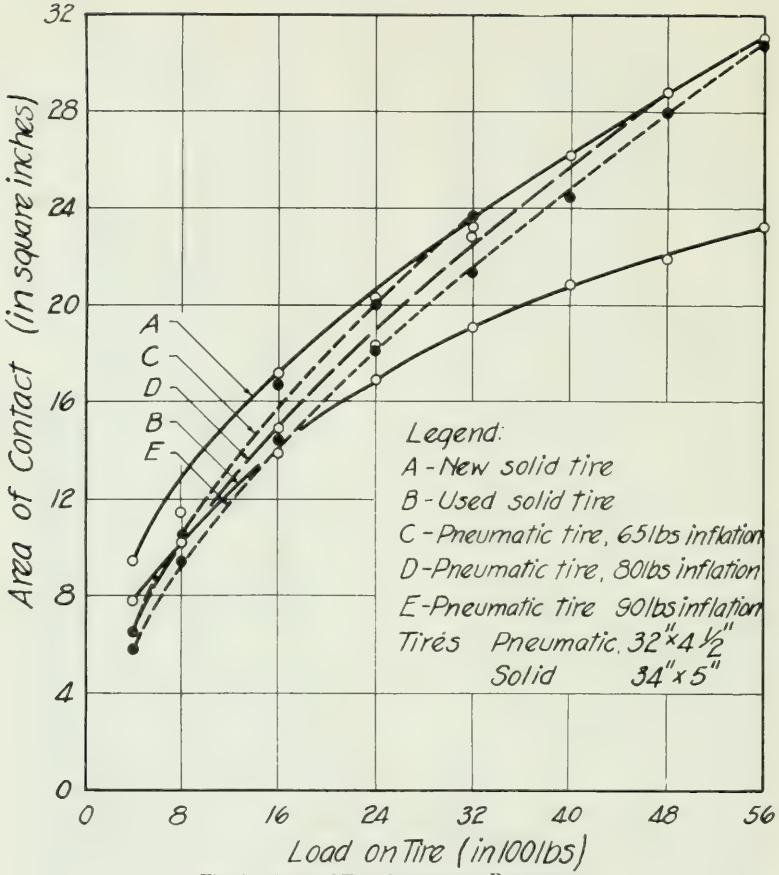

Fig. 9. Area of Tire Contact on Pavement.

In comparing solid and pneumatic tires as to their effect upon concrete the unit stress in pounds per square inch, as determined from the superimposed load, and the areas of contact must be taken into consideration. Three conditions influence this factor, namely: the external load; the condition of the tire, whether old or new; and in the case of the pneumatic tire, the degree of inflation.

The areas of contact for different tire conditions are illustrated diagramatically in Fig. 9, in which the external loads ranged from 400 to 5600 pounds. It is to be noted that there is a marked difference in the area of contact of a used solid tire and a new solid tire. The areas of contact for the various conditions were determined by means of a planimeter from the tire imprints. Each point plotted in Fig. 9 represents an average of five observations.

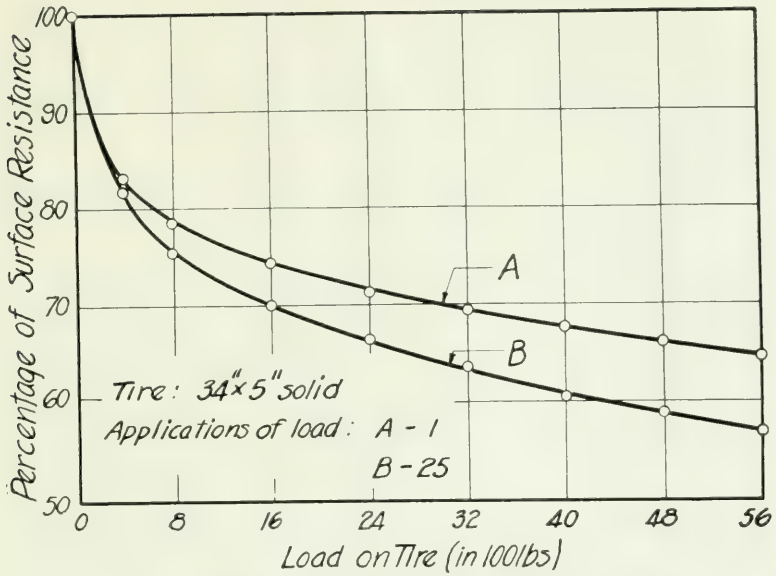

Fig. 10. Ball Resistance of Mortar Subjected to Solid Tire Loads.

Table 6. **Areas of Contact for Truck Tires Under Various Loads**

Load in Pounds	Areas of Contact (square inches)				
	Solid Tires		Pneumatic Tires—Inflation (in pounds)		
	New	Old	65	80	90
400	9.48	7.86	6.43	6.54	5.82
800	11.57	10.50	10.25	10.17	9.45
1600	17.21	14.55	16.78	14.99	13.98
2400	20.59	16.96	20.38	18.39	18.12
3200	23.27	19.16	23.78	22.95	21.43
4000	26.28	20.90		26.14	24.52
4800	28.83	21.99		28.68	28.00
5600	31.07	23.29			30.85

Series IV. Effect of Tire Loads on Original Surface of Cement Mortar.

The ball test gives promise of particular value in ascertaining the effect of tire loads upon mortar and concrete surfaces. The test is made by applying a load to a mortar slab through a rubber tired wheel and after removing the loaded wheel the exposed surface is then tested by the ball method. Four variables, namely, time between application of load and testing, number of applications of the tire loads, age of the specimens and mix of the materials have each a considerable bearing upon this effect. Figs. 10 and 11 show the effect of a 34x5 inch solid rubber tire and a 32x4½ inch pneumatic tire on cement mortar.

Curve (A), Fig. 10 shows the effect of a solid rubber tire under various loads on cement mortar. This curve represents average values for 1–1½, 1–2 and 1–2½ mortar, age 7 to 28 days. Each load was applied once, on a different area, previous to the ball test. Fifteen of these observations were averaged for each point plotted.

Curve (B), Fig. 10 was developed for the same conditions except that each load was repeated twenty-five times during a period of eight minutes preceding the ball test.

Previous to the application of any tire load, the initial resistance of each mortar slab was determined by the ball test method. In all cases this resistance was designated as 100 per cent, and each subsequent resistance after the application of a tire load was expressed as a percentage thereof. It is to be noted from the curves that the greater part of reduction in surface strength occurs for tire loads below 1600 pounds.

From these curves it is seen that a 1600 pound load on a solid tire showed the ball resistance 25.7 per cent less, twenty-five repetitions of this load 30.0 per cent less, a 5600 pound load 35.5 per cent less under one application and 43.3 per cent less under twenty-five applications.

Fig. 11 illustrates a curve for the pneumatic tire based on 85 pounds inflation and one application of each tire load. The greater part of the change in ball resistance occurs under an 800 pound tire load, being 27.7 per cent, while at 5600 pounds it is 34.9 per cent.

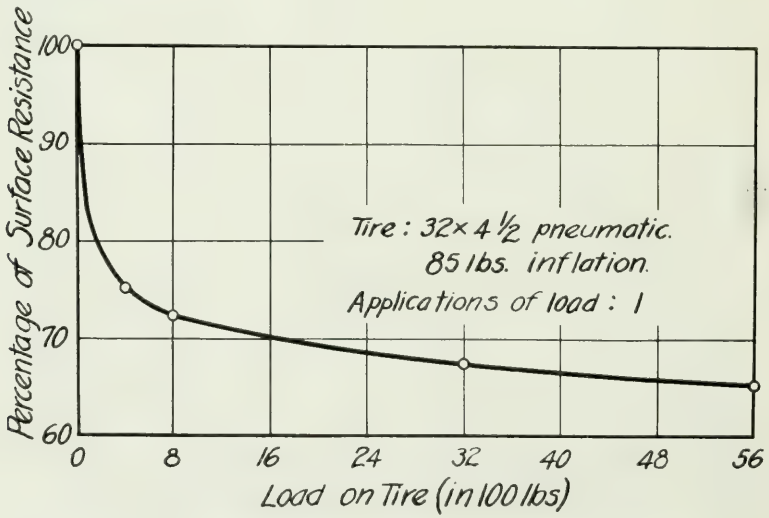

Fig. 11. Ball Resistance of Mortar Subjected to Pneumatic Tire Loads.

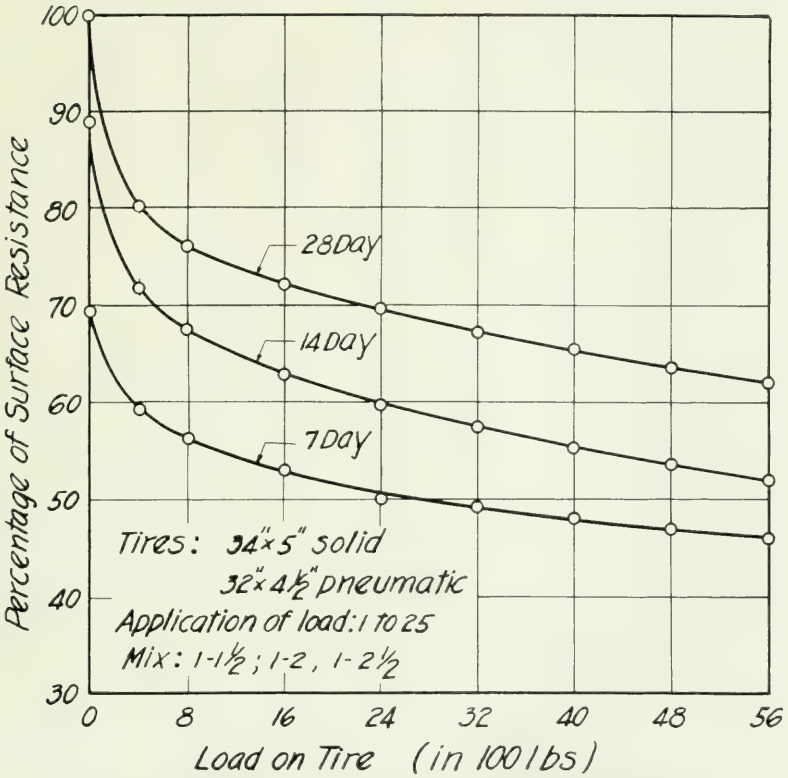

Fig. 12. Effect of Age on Mortar Subjected to Various Tire Loads.

It is appreciated that actual passenger or truck traffic would impose more varieties of forces upon road surfaces than is possible to apply by means of a testing machine. Pavements in service are constantly subjected to combined static, tractive, skidding, braking and impact forces, while by means of the testing machine only direct static loads can be applied. No attempt has been made to interpret the ball test in its relation to the surface wear of concrete roads.

Fig. 12 shows the relative effect of the same tire loads upon cement mortar at 7, 14 and 28 days. Each curve represents average value for both the solid and pneumatic tires, upon which the number of applications of load was varied from one to twenty-five. The test specimens were made of the three standard mixes 1–1½, 1–2, and 1–2½ on which the initial surface resistance for the various ages was determined subsequent to any tire loads. The initial resistance of the 28 day mortar was

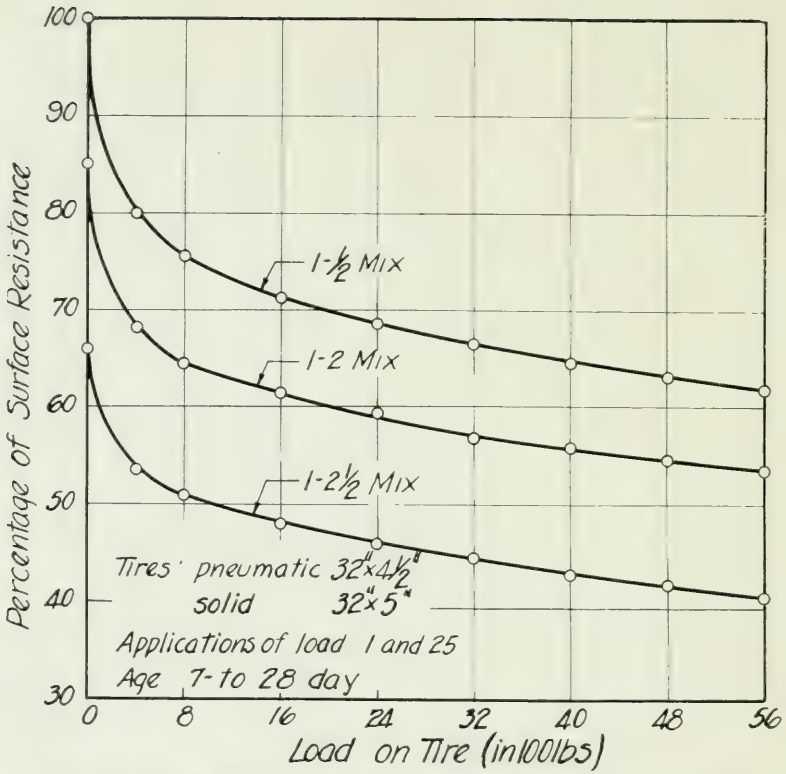

Fig. 13. Effect of Mix on Ball Resistance of Mortar Subjected to Tire Loads.

designated as 100 per cent and the other values expressed as a percentage of this. The curves for the various ages possess the same general characteristics and have about the same ratio to each other at any load as is indicated by the initial resistances.

Fig. 13 shows the relative effect of the same tire loads upon cement mortar of 1–1½, 1–2 and 1–2½ mix. Each curve represents average values, for the effect, of both the solid and pneumatic tires, upon which the number of applications of load was varied from one to twenty-five. Tests were conducted upon each mix at various ages from 7 to 28 days. In each case the initial resistance was determined previous to the application of any tire load and that of the 1–1½ mortar designated as 100 per cent, the other values being expressed as a percentage of this. These curves, like the age curves, possess the same general characteristics, having about the same ratio to each other at any load as their initial resistances indicate.

A summary of the individual results from which tables 7, 8 and 9 were compiled, show an average value of 6.1 per cent as the variation of any one observation from the average curve.

In considering the indicated change of surface strength, as shown by the ball test, under tire loads of approximately 30 per cent at legal limits of tire loading, and comparing this result with the service of pavements it must be concluded that the factor of safety against such pressures has not been reduced to a critical point.

Table 7. **Ball Resistance of Mortar Affected by Tire Loads**

No. of Applications of Load	Kind of Tire	Per Cent of Initial Resistance — Total load on Truck Wheel in lbs.								
		0	400	800	1600	2400	3200	4000	4800	5600
1	Solid	100	83.18	78.33	74.34	71.26	69.46	67.62	66.03	64.50
25	Solid	100	81.59	75.50	70.02	66.32	63.58	60.42	58.80	56.73
1	Pneumatic, 85 lbs. inflation	100	75.16	72.33			67.24			65.08

Table 8. **Effect of Age of Mortar Subjected to Various Tire Loads**

Age Days	Per Cent of Initial Resistance — Load on Truck Wheel in lbs.								
	0	400	800	1600	2400	3200	4000	4800	5600
28	100	80.25	76.17	72.44	69.81	67.43	65.53	63.67	62.03
14	89.07	71.93	67.56	63.00	59.93	57.57	55.47	53.77	52.03
7	69.65	59.30	56.30	53.02	50.09	49.50	48.03	47.10	46.20

Table 9. **Effect of Mix of Mortar Subjected to Various Tire Loads**

Mix	Per Cent of Initial Resistance — Load on Truck Wheel in lbs.								
	0	400	800	1600	2400	3200	4000	4800	5600
1-1½	100	79.88	75.53	71.37	68.60	66.52	64.62	63.10	61.86
1-2	85	68.00	64.50	61.50	59.50	57.00	55.75	54.50	53.50
1-2½	66	53.50	51.00	48.00	46.00	44.50	42.80	41.75	40.50

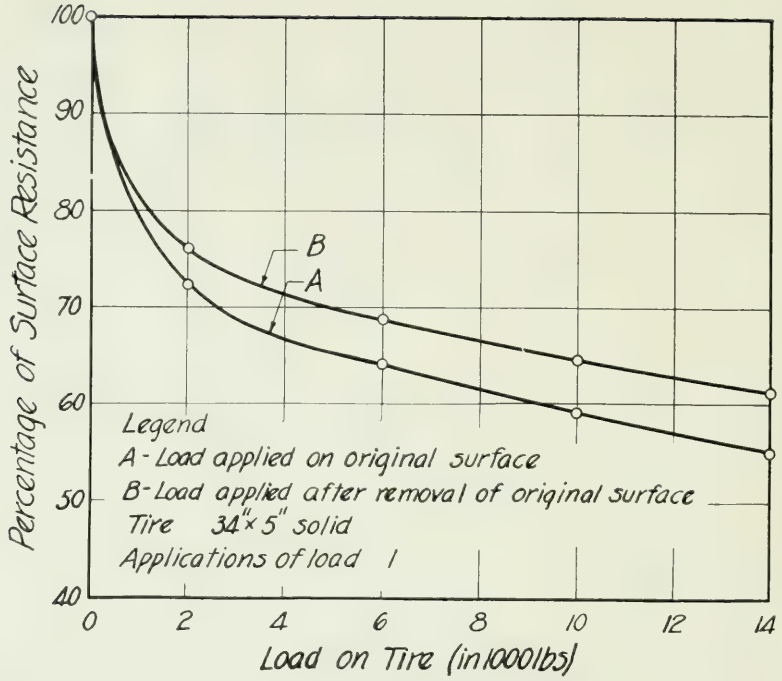

Fig. 14. Ball Resistance of Mortar at Surface and Interior.

Series V. Effect of Tire Loads upon the Original and Exposed Surfaces of Cement Mortars.

To investigate the resistance offered to tire loads at different depths in cement mortar the original surface of one-half of a test slab was removed by means of a sharp trowel to a depth of ¼ inch, immediately following the initial set of the specimen. Duplicate tests were then conducted upon the original face and the exposed surface. The initial resistance on either surface was assumed to be 100 per cent. The results of these experiments are shown in Fig. 14; each point plotted represents an average of eight observations. A summary of these results show an average value of 6.6 per cent as the variance of any one observation from the average curve.

It is to be noted from the curves that the exposed mortar possessed a higher degree of resistance than the original surface as determined by the ball test.

Table 10. **Effect of Tire Loads Upon the Original and Exposed Surfaces of Cement Mortars**

Surface Tested	Per Cent of Initial Resistance — Load on Wheel in lbs.				
	0	2,000	6,000	10,000	14,000
A	100	72.4	64.4	59.2	55.2
B	100	76.0	68.8	64.7	62.4

Note: A—Load applied on original surface.
B—Load applied on exposed surface.

Series VI Ball Resistance at Various Points within the Loaded Area of Contact.

The fact that the unit intensity of pressure between a tire and a plane surface is variable, this being especially true for solid tires, has prompted certain experiments to determine the relative effects of a tire at different points on the area of contact.

Fig. 6 illustrates a typical area of contact produced by a 34x5 inch solid tire subjected to a 1600 pound load. The total area of contact is 17.2 square inches. The decrease in ball resistance at the center of contact (A) is 25.5 per cent, as determined by a ball test at that point, while at the edge (B) it is 22 per cent. These results are indicative of the varying degree in unit intensity of pressure between a loaded tire and a plain surface.

Fig. 7 shows a similar area of contact produced by a 32x4½ inch pneumatic tire subjected to a 1600 pound tire load. The resulting area in this case is 15.0 square inches. The reduction in ball resistance at the center of contact (A) is 30.0 per cent, while the reduction at the edge (B) is 27.5 per cent. At point (C) located between the ribs of the tread, the reduction in strength is only 15.0 per cent.

Series VII. Recovery in Ball Resistance of a Cement Mortar Surface Subsequent to the Application of Tire Loads.

Cement mortar when subjected to a tire load exhibits the property of recovery in surface resistance as indicated by the ball test. An initial set or injury is usually evident and in practically all cases only a partial recovery to the original state occurs. The curves in Fig. 15 indicate this phenomenon in the case of cement mortars. The reduction in surface resistance to the ball was determined immediately after the application of an 800 pound tire load and at subsequent time intervals. The maximum

time allowed for recovery was varied in the case of each specimen, from eight hours for the seven day test, up to seventy-two hours for the twenty-eight day test. This procedure was necessary in order to e'iminate as much as possible an increase in strength due to an increase in age.

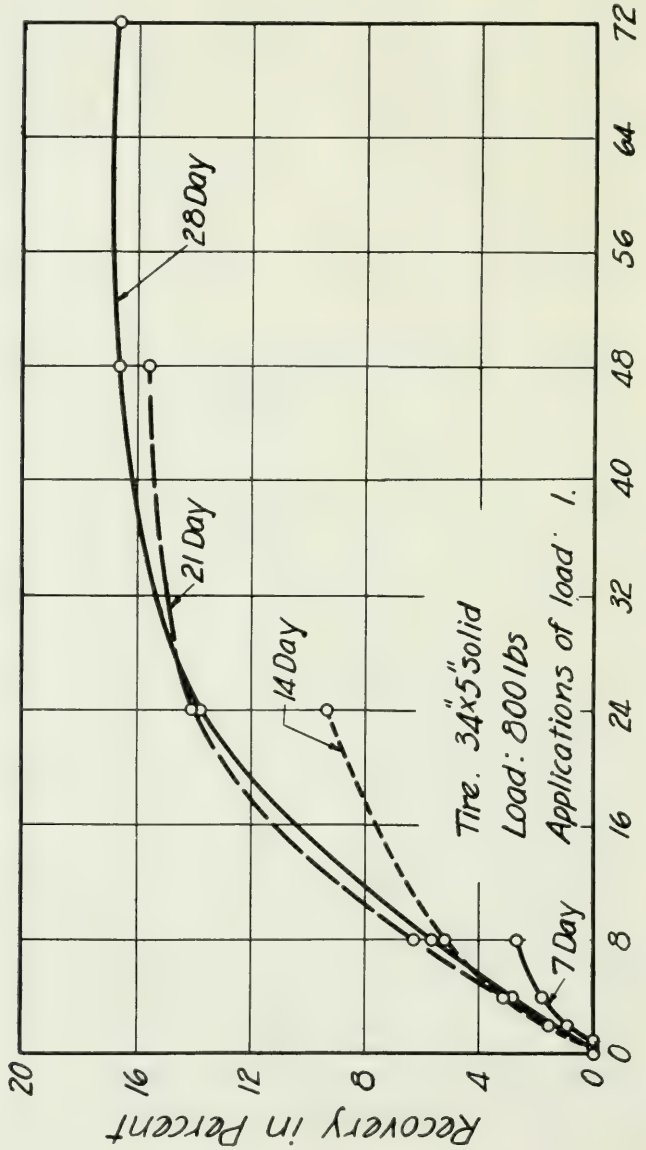

Fig. 15. Recovery of Ball Resistance of Mortar.

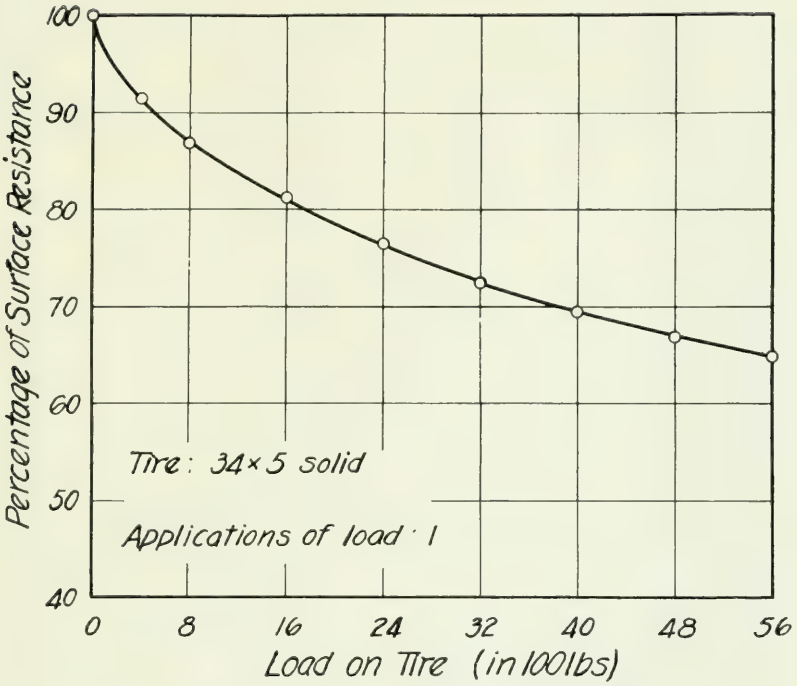

Fig. 16. Ball Resistance of 1:2:4 Concrete Subjected to Tire Loads.

In all cases the surface strength recovers to some extent with time, a maximum being attained at the end of forty-eight hours. Additional time has no effect upon this factor as indicated by the curves. A mortar surface will recover about 16 per cent or approximately one-half of its initial loss, caused by an 800 pound tire load, if given sufficient time.

Table 11. **Recovery in Ball Resistance of Cement Mortar Subsequent to the Application of a Tire Load**

Age of Specimen at Time of Test in Days	Per Cent of Recovery							
	Time for Recovery in Hours							
	½	1	2	4	8	24	48	72
7	0.00	0.00	0.89	1.76	2.63			
14	0.00		1.56		5.20			
21	0.00		1.56	3.12	6.25	14.10	15.60	
28	0.00		1.39	2.78	5.55	13.88	16.65	16.65

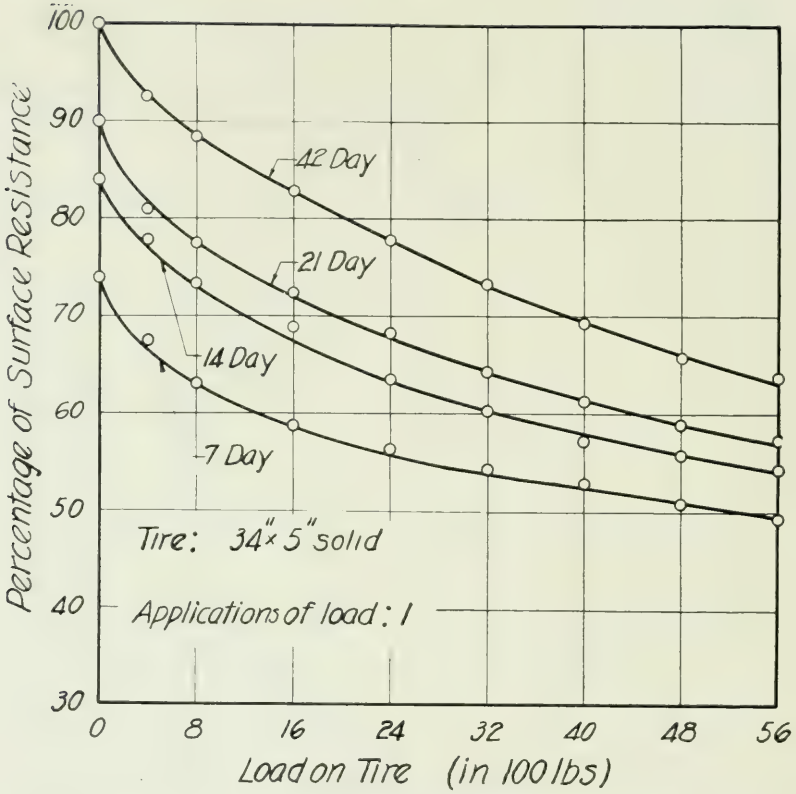

Fig. 17. Effect of Age on 1-2-4 Concrete Subjected to Tire Loads.

Series VIII. Effect of Tire Loads upon 1-2-4 *Concrete.*

In order to enhance the practical value of the ball test in connection with cement products, a series of tests was conducted upon concrete specimens of a 1-2-4 mix by volume. The same general consistent results were obtained (see Figs. 16 and 17) as were obtained and heretofore discussed in the case of the experiments upon mortar specimens as shown in Series IV. It is to be noted that the slope of the concrete curves are the more gradual. However the total decrease under 5600 pounds tire load is practically the same for both concrete and mortar. Each point plotted in Fig. 16 and 17 represents an average of three observations, which show an average value of 5.5 per cent as the variance of any one observation from the average curve.

The grading of the coarse aggregate and the other properties of the materials used in the concrete specimens were as follows:

Table 12. Mechanical Analysis of Gravel Tyler Standard Sieves

	Total Per Cent Retained on Each Sieve			
Sieve sizes	1½	¾	⅜	No. 4
Per Cent	0.0	8.8	60.6	100.0

Fineness Modulus of coarse aggregate 6.69

Weight per cubic foot of coarse aggregate ... 104.9 pounds.

Fine Aggregate—Same as used in mortar specimens (see Tables 2 and 3).

Fineness Modulus of combined aggregates ..... 5.45.

Slump (4—8x12 inch cone) ..... 2 inches.

Table 13. Ball Resistance of 1-2-4 Concrete Affected by Tire Loads

No. of Applications of Load	Kind of Tire	Per Cent of Initial Resistance								
		Load on Wheel in lbs.								
		0	400	800	1600	2400	3200	4000	4800	5600
1	Solid Rubber	100	91.5	86.9	81.2	76.5	72.5	69.5	66.9	64.9

Table 14. Effect of Age on Ball Resistance of 1-2-4 Concrete Subjected to Tire Loads

Age Days	Per Cent of Initial Resistance								
	Load on Wheel in lbs.								
	0	400	800	1600	2400	3200	4000	4800	5600
42	100	92.5	88.5	83.0	78.0	73.5	69.5	66.5	64.0
21	90	81.0	77.5	72.5	68.5	64.5	61.5	59.0	57.5
14	84	78.0	73.5	69.0	63.5	60.5	57.5	56.0	54.5
7	74	67.5	63.0	59.0	56.5	54.5	53.0	51.0	49.5

VIII. CONCLUSIONS

1. The ball test applied to cement products composed of mortar affords a valuable and convenient means of determining the compressive strength.

2. The ball test is a very reliable index of strength for any age or mix.

3. By means of the ball test material already in place may be tested.

4. The ball test will be useful to contractors and inspectors in determining accurately when a concrete road may be opened for traffic, or the forms removed from a structure.

5. The ball test indicates a new means of studying the following questions in connection with concrete pavements:

(a) The effect of wheel loads upon surface strength.
(b) The effect of different types of tires upon surface strength.
(c) The effect of tire inflation upon surface strength.
(d) The distribution of damage on any area of contact.
(e) The effect of impact.
(f) The recovery of surface strength.

LIST OF PUBLICATIONS OF THE ENGINEERING EXPERIMENT STATION

PAMPHLET. The Engineering Experiment Station of Purdue University, 1917. (Out of Print).

CIRCULAR No. 1. Lightning Protection, by C. F. Harding, 1918.

BULLETIN No. 1. Flow of Water Through One and One-half Inch Pipe and Valves, by F. W. Greve, Jr., 1918.

BULLETIN No. 2. Electric Ranges, by C. W. Piper, 1919.

BULLETIN No. 3. Coefficients of Discharge of Sprinkler Nozzles, by F. W. Greve, Jr., and W. E. Stanley, 1919.

BULLETIN No. 4. Electric Driven Water Works in Indiana, by D. D. Ewing and G. C. Blalock, 1919.

BULLETIN No. 5. The Carburetion of Gasoline, by O. C. Berry and C. S. Kegerreis, 1920.

CIRCULAR No. 2. Preservative Treatment of Wood Poles, by R. V. Achatz, 1920.

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BULLETIN No. 6. Sewage Disposal for Residences and Small Institutions, by R. B. Wiley, 1920.

BULLETIN No. 7. Tests of Road Materials of Indiana, by Testing Materials Staff, 1921.

BULLETIN No. 8. Flow of Water Through Spiral Riveted Steel Pipe, by F. W. Greve and R. R. Martin, 1921.

BULLETIN No. 9. The Production of Nitric Oxides and Ozone by High Voltage Electric Discharges, by K. B. McEachron and R. H. George, 1922.

BULLETIN No. 10. Truck Operating Costs, by Ben H. Petty, 1923.

BULLETIN No. 11. Effect of Speed on Mixture Requirements, by C. S. Kegerries and G. A. Young, 1923.

BULLETIN No. 12. Ball Test Applied to Cement Mortar and Concrete, by R. B. Crepps and R. E. Mills, 1923.

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The formal organization of the Engineering Experiment Station of Purdue University was approved by the Board of Trustees on February 28, 1917.

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